NEW JERSEY GEOLOGICAL SURVEY

Technical Guidance

A Recharge-Based Nitrate-Dilution Model for New Jersey

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NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

DIVISION OF SCIENCE, RESEARCH AND TECHNOLOGY

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Cover Illustration:

Schematic illustration of effluent leaving the lateral distribution field of a domestic on-site subsurface wastewater disposal system.
Figure from the 'Septic System Owner's Guide' web site of the Univ. of Minnesota, College of Agricultural, Food, and Environmental Sciences, Extension Service: http://www.extension.umn.edu/distribution/naturalresources/DD6583.html

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Technical Guidance

A Recharge-Based Nitrate-Dilution Model for New Jersey

by

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New Jersey Department of Environmental Protection
Science and Technical Programs
Division of Science, Research and Technology
Geological Survey
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2001

Conversion Factors

multiply inch-pound units	by	to obtain metric (SI) units
	LENGTH	
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	AREA	
square foot (ft^2)	0.0929	square meter (m^2)
acre (ac)	0.4047	hectare (he)
square mile (mi^2)	2.5880	square kilometer (km^2)
	VOLUME	
cubic inches (in^3)	16.38	cubic centimeters (cm^3)
cubic feet (ft^3)	0.02832	cubic meters (m^3)
gallons (gal)	3.785	liters (L)
gallons (gal)	3.785×10^{-3}	cubic meters (m^3)
	FLOW RATE	
gallons/minute (gpm)	0.06309	liters/second (L/sec)
gallons/day(gpd)	3.785	liters/day (L/day)
cubic feet/second (ft^3/s)	0.02832	cubic meters/second (m^3/s)

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http://www.state.nj.us/dep/njgs/index.html

A Recharge-Based Nitrate-Dilution Model for New Jersey

Table of Contents

Figures

Tables

"But as the habitations were gradually built up and the population increased, it was noticed that the water in the wells, especially in the more populous portions, was rapidly losing its pristine purity, and was becoming hard, impotable and injurious to health…"

> Municipal Report of the City of Charleston, South Carolina, 1881 as reported by Chapelle, 1997, p.157.

"In general, aquifers will return small quantities of untreated sewage to clean, pristine water fairly quickly. As long as the amount of sewage did not exceed the "assimilative capacity" of the underlying aquifer…"

> Chapelle, 1997, p.162 discussing the correlation between increasing population (and privies) and the decline of water quality of wells in Charleston, South Carolina during the 1800's.

A Recharge-Based Nitrate-Dilution Model for New Jersey

ABSTRACT

The effluent from domestic on-site subsurface wastewater disposal systems can degrade ground-water quality. Where these systems are too close together the cumulative impact may exceed the natural ability of the environment to clean and dilute the effluent, resulting in elevated concentrations of contaminants in ground water. One contaminant of concern in effluent is nitrate. Nitrate is produced in the unsaturated zone beneath a disposal system by the microbial transformation of ammonia. The primary drinking water criterion for nitrate is 10 mg/L. Concentrations greater than this can cause methemoglobinemia in infants and are a health threat to the elderly. Additionally, elevated nitrate concentrations are an indication of the possible presence of other contaminants in ground water.

This report presents a methodology that enables the user to estimate the average area required per disposal system to generate enough ground-water recharge to dilute that system's effluent to acceptable levels. The recharge-based nitrate-dilution model described here is a synthesis of two independent models: a mass-dilution model and the New Jersey Geological Survey's (NJGS) ground-water-recharge method.

The mass-dilution model is modified from the Trela-Douglas nitrate dilution model. The Trela-Douglas nitrate dilution model has been used in New Jersey for more than 20 years to estimate nitrate concentrations in ground water from on-site subsurface wastewater disposal systems. As originally published, the model required data on household occupation rate, per capita water use, lot size per home, recharge rate, and the nitrate concentration in the effluent. This method has been revised to require only the household occupancy rate and the per capita nitrate loading rate. It also accounts for reduction in recharge due to impervious cover on the developed lot.

The NJGS' ground-water-recharge method is a water-budget approach that estimates average annual ground-water recharge based on land use, soil type and a municipality-based climate factor. It is applicable only to New Jersey.

The two underlying models are combined to produce a recharge-based nitrate-dilution model. This requires an additional parameter, a nitrate target. The target is the concentration that nitrate in the ground-water should not exceed after dilution is taken into account. The model's result is an estimate of required acres per system which will provide enough recharge to dilute the nitrate emitted by an on-site subsurface wastewater disposal system to meet the specified water-quality target. A spreadsheet titled 'nj_no3_dilution_v41.xls' is provided to implement this model.

The assumptions contained in the two underlying models apply to the resultant model. The primary assumptions made by the nitrate dilution model are: complete and uniform mixing of wastewater, the only water available to dilute the nitrate loading is recharge on the pervious areas of the lot, molecular dispersion and diffusion are insignificant, and denitrification in the ground water is insignificant. The NJGS' ground-water-recharge methodology assumes that an annual average water-budget approach, whereby all water which infiltrates below the root zone becomes recharge, is appropriate. It also is designed to be applied at a map scale of 1:24,000.

The methodology is designed to be used as a planning tool. It cannot be used to accurately estimate nitrate concentrations in a plume at specific distances downgradient of an individual wastewater disposal system. It can be used, however, to estimate regional concentrations of nitrate in ground water resulting from residential developments with on-site wastewater disposal systems.

Reasonable nitrate-loading rates for New Jersey are 3 people per home and 10 pounds of nitrate per person per year. The occupancy rate may be altered if development- or township-specific values are more reasonable. The per capita nitrate loading rate should not be altered without significant research into appropriate loading rates.

Nitrate targets depend on specific program and regulatory requirements. In general, an antidegradation approach as defined in New Jersey's ground-water-quality regulations (N.J.A.C. 7:9-6) is appropriate. This leads to a nitrate target of about 5.2 mg/L in most areas of New Jersey. However, in areas of special ecological concern, lower targets may be appropriate.

This method addresses just one factor in determining how dense a development a specified area can sustain without having undesirable effects on the environment. Other factors, such as other non-point source contaminant loading, infrastructure capacity, open-space requirements, and ecological impacts must be addressed in determining the actual carrying capacity of a specified tract of land.

An earlier version of this model, titled "A model of residential carrying capacity for New Jersey based on water quality," estimated nitrate loadings based on per capita water use rates and concentration of nitrate in the effluent. This requires two parameters, each with a wide range of possible values. Using the actual per capita nitrate loading reduces uncertainty. Additionally, earlier versions allowed the nitrate to be diluted by the volume of waste water, but allowed for additional sources of nitrate input. This current approach only allows for dilution by infiltration on pervious portions of the lot, but only accounts for nitrate loadings from the subsurface wastewater disposal system.

This document, and accompanying spreadsheet, supercede earlier versions. The spreadsheet may be revised if appropriate.

INTRODUCTION

The New Jersey Geological Survey (NJGS) has provided estimates of water-resource-based carrying capacity for more than 30 years. Early studies of the geology and ground-water resources of rural and developing areas used aquifer characteristics to develop recommendations for appropriate residential lot sizes where served by on-site subsurface waste-water disposal systems (Widmer, 1965; Kasabach, 1966; Miller, 1974). During the late 1970's the NJGS employed the nitrate dilution model of Trela and Douglas (1978) to provide the Pinelands Commission with recommendations for appropriate residential lot sizes based on water-quality criteria. The same principles were applied by Saunders and others (1979) in evaluating the possible impact of a proposed subdivision. At that time the primary drinking water criterion of 10 milligrams per liter (mg/L) nitrate-nitrogen and the surface-water quality criterion of 2 mg/L for state category 1 surface waters were applied in setting water-quality goals for use in the model, depending on the geographic area of concern. The Trela-Douglas model has been applied in several locations outside of the Pinelands to determine appropriate residential densities based on water quality.

The N.J. Department of Environmental Protection, Division of Water Quality, has used a version of the Trela-Douglas model in conjunction with the NJGS' ground-water recharge model since 1995 to determine the effect of developments of 50 or more units with on-site subsurface waste-water disposal systems on ground-water quality (F. Bowers, 2001, personal communication). In this application, a nitrate target of 5.2 mg/l is used.

This recharge-based nitrate-dilution model involves coupling a modified Trela-Douglas model with NJGS' ground-water recharge model (Charles and others, 1993) to develop estimates of appropriate residential lot sizes to meet state water-quality goals for nitrate-nitrogen (nitrate). The ground-water-recharge component of the model incorporates variations in land use, soil type and climate observed throughout the State.

The goal of this model is to provide a tool that can be used, in conjunction with other relevant tools, to help determine the sustainable residential carrying capacity of land in New Jersey.

Acknowledgements

We gratefully acknowledge reviews by Dr. Fred Bowers of the NJDEP's Bureau of Non-point Pollution Control, Dr. John Trela of Dan Raviv Associates and Emmanual Charles of the U.S. Geological Survey.

The figure on the cover is from a web site titled 'Septic System Owner's Guide' maintained by the Univ. of Minnesota, College of Agricultural, Food, and Environmental Sciences, Extension Service:

http://www.extension.umn.edu/distribution/naturalresources/DD6583.html

NITRATE AND WATER QUALITY

Nitrate in ground water.

The present analysis focuses on nitrate concentrations in ground water resulting from on-site subsurface wastewater disposal systems. Other constituents could also be addressed. However, nitrate was chosen for several reasons: (1) it generally occurs naturally only at low levels; (2) elevated levels are generally an indicator of anthropogenic activities; (3) it is relatively stable and mobile and thus a good tracer of water-quality changes, and; (4) there are human and ecological concerns associated with excess levels of nitrate. Each of these factors is discussed below.

In this report nitrate is referred to in units of nitrate-nitrogen, in mg/L. (A concentration of 10 mg/L nitrate-nitrogen is equivalent to 44 mg/L of the nitrate ion (Hem, 1985)). In general, all measurements in this report are converted from actual ionic concentrations to equivalent nitrate-nitrogen concentrations.

Nitrate is generated by biological oxidation of organic or inorganic nitrogen. This process is known as nitrification. The principal end product, nitrate, is a stable and mobile anionic species under the most prevalent ground-water conditions in the water-table aquifers of New Jersey. Nitrite is also an intermediate product of nitrification, but is less stable and commonly occurs in much lower concentrations than nitrate. For planning purposes it is commonly assumed that by the time the leachate reaches the water table the ammonia has been entirely converted to nitrate.

This report is primarily concerned with nitrate in ground water produced by on-site subsurface wastewater disposal systems. A net nitrate-nitrogen loading rate of 10 pounds per person per year is a reasonable value (table 1). Nitrate accumulation in ground water due to these systems has been recognized for many years (Todd and McNulty, 1974). Nitrate is produced from nitrification that occurs in the unsaturated zone beneath a septic disposal bed. This organic and inorganic nitrogen is converted to nitrite and nitrate as the wastewater effluent migrates downward to the water table. Nearly complete conversion from ammonia to nitrate and nitrite occurs in unsaturated, well-aerated soil below septic fields (Walker and others, 1973b).

The accumulation of inorganic nitrogen in ground water in residential areas served by on-site wastewater systems is well documented (Tinker, 1991, Murphy, 1992, Hantzsche and Finnemore, 1992). Because nitrate in its inorganic form is highly stable and mobile under normal ground-water conditions, it can migrate readily. Thus, areas downgradient of a development utilizing these systems commonly show elevated nitrate levels in the ground water.

Nitrate concentrations in ground water in undeveloped areas are typically low, averaging less than 1 mg/L (Stackelberg and others, 1997). Anthropogenic sources, such as residential development and agriculture, elevate nitrate concentrations. Concentrations of nitrate in ground water in agricultural areas often exceed the primary drinking water standard of 10 mg/L. In developed and developing areas, concentrations of nitrate are typically in the range of 1 and 3 mg/L (MacLeod and others, 1995).

The NJGS maintains a program to collect, analyze, and report information on naturally occurring water quality. Data from this program were compiled in conjunction with water-quality studies by the U.S. Geological Survey (USGS) to determine ambient concentrations of nitrate-nitrogen or nitrate/nitrite in ground water (table 2). This table groups studies by physiographic province.

The data in table 2 include analyses from areas of mixed land use and from agricultural areas. Nitrate concentrations in samples from agricultural areas are elevated, as expected, showing the effects of land application of fertilizers. If predominantly agricultural area studies are eliminated, median nitrate concentrations for non-agricultural areas range from 0.03 to 3.5 mg/L.

Other sources of nitrate

There are other potential sources of nitrate in ground water. This includes nitrate in precipitation, lawn fertilizers and decomposition of plant material and animal waste. Nitrate loading rates from these sources can vary widely. Typically nitrate levels in ground water in agricultural areas are higher than in residential areas (Hem, 1985). Elevated nitrate concentrations attributable to the use of fertilizers can also be found in urban areas (U.S. Geological Survey, 1999; Carleton and Vowinkel, 1996).

Quantifying actual nitrate loading rates to the ground water from these sources is difficult and beyond the scope of this project. One important mitigating factor is that nitrogen from these sources must travel downward through the root zone in order to enter the ground water. Plant uptake may greatly decrease the nitrate concentrations during this journey. This is in contrast to the nitrate in the effluent from a subsurface disposal system, which is injected into the ground below the root zone and is less subject to diminution by plant uptake.

Stability of nitrate (denitrification)

Nitrate is generally stable in ground water and most of the attenuation of nitrate levels in ground water is the result of dilution by better quality recharge water. However, denitrification may occur in ground water where the conditions are favorable. Denitrification is the microbial conversion of nitrate and nitrite to dinitrogen (N_2) gas (Korom, 1992).This process can reduce the concentration of nitrate in ground water but does not commonly occur in most areas served by domestic on-site subsurface wastewater disposal systems.

Denitrification requires four primary conditions: (1) appropriate bacteria; (2) nitrogen oxides; (3) organic carbon; and (4) anaerobic conditions (Desimone and Barlow, 1996; Korom, 1992; Firestone, 1982). All conditions are seldom combined in the proper proportions in ground water. This is particularly true in recharge areas where ground-water depths are commonly great, aerobic conditions prevail, and carbon has been oxidized from the aquifer.

Denitrification requires a suitable electron donor. This is commonly organic carbon, but the aquifer matrix may also serve as an electron donor. Generally only a small fraction of naturally occurring organic carbon in soils or aquifer sediments is labile (Desimone and Barlow, 1996) because it has been subjected to aerobic ground-water for thousands of years. If the concentration of nitrate-nitrogen in the ground water exceeds that of organic carbon, the organic carbon fraction is insufficient to bring about denitrification (Korom, 1992). Thurman (1985) states that most ground water has organic carbon concentrations of less than 2 mg/L.

Denitrification also requires anaerobic conditions. Gillham and Cherry (1978) found that denitrification doesn't take place if the concentration of dissolved oxygen exceeds 2.0 mg/L.

Denitrification in ground water may be carbon or nitrate limited, or oxygen suppressed, depending on concentrations of these constituents in ground water. Walker and others (1973a) found that denitrification beneath septic disposal fields in unsaturated sandy soils may be insignificant due to the lack of anaerobic conditions and organic matter.

In a study of a nitrate plume on glacial sands in Cape Cod, a denitrification rate equivalent to 1.5 mg/L as nitrogen per 100 feet of horizontal flow was observed (Desimone and Barlow, 1996). On a mass basis, denitrification transformed about 2 percent or less of the total mass of nitrogen in the plume of septic effluent per 100 feet of flow. Foster and others (1985), in a study of the Lincolnshire Limestone in England, determined a nitrate reduction rate of 10 mg/L over a horizontal flow distance of 2 km after 100 days. These researchers suspected that some of the organic carbon acting as an electron donor in the denitrification process was probably derived from the limestone aquifer matrix itself. They determined also that if the concentration of nitrate in the ground water exceeds that of organic carbon, the carbon will be insufficient to bring about denitrification.

One factor often overlooked is the persistent, cumulative effects of the build-up of nitrates during long-term sewage-disposal practice at a given site (Hantzsche and Finnemore 1992). This is the result of an imbalance in the factors governing the process (for example, by a depletion of organic carbon).

Because of the variability of controlling factors, such as soil and aquifer geochemistry, the rate of in-place denitrification is difficult to quantify. Korom (1992), in a review of research on denitrification, concludes that, “our current capabilities to predict an aquifer’s denitrification characteristics are site specific at best.” Where it has been documented, denitrification rates are commonly low or occur only after great lengths of time or flow paths.

Human and ecological concerns with nitrate

Nitrate in sufficient concentrations has potentially adverse health effects when ingested by vulnerable humans and has adverse effects on ecosystems. Infants who consume water with nitrate-nitrogen concentrations greater than 10 mg/L may be afflicted with methemoglobinemia (Hem, 1985). In addition, elevated nitrate concentrations may be an indicator of the presence of other contaminants in ground water, such as pesticides.

Shallow ground water generally discharges to nearby surface water. This is termed baseflow. The quality of the baseflow can affect surface-water quality, especially during low flow times. If the base flow has elevated nitrate concentrations then it may encourage the growth of algae in the surface water. This may affect aquatic species in the streams (U.S. Geological Survey, 1999).

Table 1. Reported nitrate loading rates

Data Source	Reported Parameter	Pounds/person/year
Laak, 1980	total nitrogen	10.4
Ligman and others, 1974	total nitrogen	14.2
Metcalf & Eddy, Inc., 1991	total Kejdahl nitrogen	9.9
Siegrist and others, 1976	total nitrogen	5.4
U.S. EPA, 1980	total Kejdahl nitrogen	9.13

Table 2. Minimum, median and maximum nitrate values reported in selected studies of ground water in New Jersey

Regional setting	Aquifer and areal development	Parameter	Number of Samples	Concentration (mg/L) Minimum	Median	Maximum	Source
Newark Basin	sedimentary bedrock	nitrate-nitrogen	55	0.1	1.6	7.4	Serfes, 1994
	sedimentary bedrock	nitrate + nitrite	14		1.1		Czarnik and Kozinski, 1994
	stratified drift	nitrate + nitrite	18		0.5		
Highlands	Precambrian crystalline bedrock	nitrate + nitrite			1.9		Serfes, in press
	Precambrian crystalline bedrock	nitrate-nitrogen	45	<0.1	0.76	4.7	
	Precambrian crystalline bedrock	nitrate-nitrogen	16	<.01	0.38	2	Nicholson and others, 1996
	Kittatinny Limestone (carbonate bedrock)	nitrate-nitrogen	30	<.01	3.15	9.1	
	stratified drift	nitrate-nitrogen	27	<.1	2.3	5.9	
Valley and Ridge	Martinsburg Formation (sedimentary bedrock)	nitrate-nitrogen	26	<0.05	0.16	5.3	Serfes, in press
	Kittatinny Limestone (carbonate bedrock)	nitrate-nitrogen	26	<0.05	0.39	5.6	
Coastal Plain	New Jersey	nitrate-nitrogen	663	0.04	0.5	26	Knobel, 1985
	upper PRM aquifer	nitrate-nitrogen	37		0.3		Barton and others, 1987
	middle PRM aquifer	nitrate-nitrogen	34		2.3		
	PRM aquifer (upper + middle)	nitrate-nitrogen	71		1.7		
	PRM aquifer system	nitrate + nitrite	262	0	0.03	0.84	Fusillo and Voronin, 1981
	PRM aquifer system, undeveloped areas	nitrate-nitrogen	15 total		0.1		Vowinkel and Tapper, 1995
	PRM aquifer system, agricultural areas	nitrate-nitrogen			8.5		
	PRM aquifer system	nitrate + nitrite	575	0	0.6	198	Fusillo and others, 1984
	upper PRM aquifer	nitrate + nitrite	133	<0.1	<0.1	13	Harriman and others, GSR 1989
	upper PRM aquifer	Kjeldahl nitrogen	133	<0.2	0.3	2.8	
	lower PRM aquifer	nitrate + nitrite	106	<0.1	<0.1	13	
	lower PRM aquifer	Kjeldahl nitrogen	106	<0.2	0.3	5.4	
	PRM aquifer system	nitrate + nitrite	116	<0.1	<0.1	23	Ervin and others, 1994
	Kirkwood/Cohansey aquifer, undeveloped areas	nitrate-nitrogen	99		<.01		Vowinkel and Tapper, 1995
	Kirkwood/Cohansey aquifer, agricultural areas	nitrate-nitrogen			7.2		
	Kirkwood/Cohansey aquifer, domestic wells	nitrate-nitrogen	837		1.9		MacLeod and others, 1995
	Kirkwood/Cohansey aquifer, agricultural irrigation wells	nitrate-nitrogen	13		3.4		
	Kirkwood/Cohansey aquifer, commercial wells	nitrate-nitrogen	16		2.75		
	Kirkwood/Cohansey aquifer	nitrate + nitrite	154	<0.1	0.08	10.5	Harriman and Voronin, 1985
	Kirkwood/Cohansey aquifer agricultural areas	nitrate-nitrogen	29	0.097	8.2	27	Szabo and others, 1997
	Kirkwood/Cohansey aquifer non-agricultural areas	nitrate-nitrogen	13	<0.1	0.3	3	
	Kirkwood/Cohansey aquifer, undeveloped areas	nitrate-nitrogen	13		.07		Stackelberg and others, 1997
	Kirkwood/Cohansey aquifer, new urban areas	nitrate-nitrogen	30		2.6		
	Kirkwood/Cohansey aquifer, old urban areas	nitrate-nitrogen	14		3.5		
	Kirkwood/Cohansey aquifer, agricultural areas	nitrate-nitrogen	15		13.0		

Table 2. Minimum, median and maximum nitrate values reported in selected studies of ground water in New Jersey (cont.)

Regional setting	Aquifer and areal development	Parameter	Number of Samples	Concentration (mg/L) Minimum	Median	Maximum	Source
Coastal Plain,	Kirkwood/Cohansey aquifer, All wells tested	nitrate-nitrogen	159		3.1		Kozinski and others, 1995
	Kirkwood/Cohansey aquifer, agricultural areas, Bridgeton Fm. present	nitrate-nitrogen	?		6.0		
	Kirkwood/Cohansey aquifer, agricultural areas, no Bridgeton Fm. present	nitrate-nitrogen	?		2.1		
	Kirkwood/Cohansey aquifer, no agriculture within 500 ft, no Bridgeton	nitrate-nitrogen	?		0.25		
	Kirkwood/Cohansey aquifer	nitrate + nitrite	246	<.01	0.08	10.5	Barringer and others, 1997
	Kirkwood/Cohansey aquifer	nitrate-nitrogen	5	0.13	0.36	3.5	Watt and Johnson, 1992
	Kirkwood/Cohansey aquifer	nitrate + nitrite	19	0.2	0.25	5.75	Watt and others, 1994
	Kirkwood/Cohansey aquifer	nitrate-nitrogen	10	0.01	0.01	0.01	Lacombe and Rosman, 1995
	Kirkwood/Cohansey aquifer	nitrate-nitrogen	25	<.05	0.1	6	Johnson and Watt, 1996

For a description of the aquifers of New Jersey see Herman and others (1998).

NITRATE-DILUTION MODEL

The basic nitrate-dilution model of Trela and Douglas (1978) was developed to estimate the land area necessary to dilute nitrate emanating from on-site subsurface wastewater disposal systems to reach a specified concentration in ground water. It was first applied in New Jersey in the Pine Barrens of the Coastal Plain.

Trela-Douglas Model Assumptions

A series of assumptions are inherent in applying the Trela-Douglas nitrate-dilution model. These assumptions, and some of their implications, are:

- *Complete and uniform mixing of wastewater and recharge takes place at the water table.* The actual behavior of ground-water flow and contaminant plumes suggests that the wastewater plume would move in a concentrated slug, with higher concentrations at the center. However, on a regional basis this assumption is justified.
- *The only water available to dilute wastewater is recharge.* On an individual lot only that recharge which falls directly over or upgradient of the leachate plume will dilute it. This assumption ignores mixing of the plume with upgradient water. On a regional sense, however, this assumption is reasonable because one cannot guarantee the quality of upgradient water.
- *Molecular dispersion and diffusion are not taken into account*. Diffusion and dispersion are more active at the peripheries of the plume and may not affect the core significantly, especially along short distances.
- *The entire residential lot area provides recharge to dilute the effluent.* No account is made for water diverted by roof tops and paved areas to storm drains.
- *Denitrification is absent*. Nitrate concentrations in ground water are lowered only by dilution, the addition of more dilute recharge water.
- *There is a one-to-one correspondence between homes and disposal systems*. Each home has only one disposal system and each disposal system serves only one home.

Some of the above assumptions would result in an underestimate of nitrate concentrations from on-site disposal systems whereas others would result in an overestimate. The model is not intended to accurately show the precise concentration of nitrates along ground-water flow paths, but is a tool to estimate overall loading of inorganic nitrogen to ground water from subsurface wastewater disposal systems.

Modification of Trela-Douglas model

The nitrate dilution model of Trela and Douglas (1978) is a mass-balance model. It assumes the mass of nitrate added to the ground water is the same as that which leaves the lot in ground water at the downgradient side. It was intended to estimate nitrate concentrations in ground water downgradient of a home with an individual on-site waste disposal system (typically a septic tank with a leachate field) in the Pine Barrens of New Jersey.

The basic Trela-Douglas mass-balance equation assumes that the mass of nitrate leaving the lot is the result only of nitrate added by the septic system. The mass is calculated bas the product of the effluent volume and concentration of nitrate in the effluent. The volume of water leaving the lot is the volume of water from the septic system added to the volume of recharge.

The basic Trela-Douglas model approach is modified in three ways. (1) The nitrate added to the site is expressed as a function of the number of people per home and the per capita nitrate loading rate. (2) Only water recharging on the site is assumed to dilute the nitrate. (3) Only the permeable portion of the lot is assumed to contribute recharge. This is expressed as:

$$L_i = L_o \qquad (1)$$

where

L_i = nitrate loading rate
L_o = nitrate leaving lot in ground water

The amount of nitrate added to the site is expressed as :

$$L_i = HM \qquad (2)$$

where

H = number of people per home
M = per capita nitrate loading rate

The second modification is to the amount of nitrate leaving the site. This is expressed as:

$$L_o = A_pRC_q \qquad (3)$$

where

A_p = amount of permeable land per home
R = recharge rate
C_q = concentration of nitrate in ground water at the downgradient end of the lot

The third modification to the basic Trela-Douglas model involves the consideration of impervious cover. If part of the lot is not permeable, (such as roof tops or paved areas) it may not contribute recharge. If all precipitation falling on the impervious surface discharges off the lot less recharge is available to dilute the nitrate in the effluent.

Table 3 relates an estimated impervious cover to lot size (U.S. Dept. of Agriculture, 1986). Fitting a power series to the data with the percentage impervious cover as the dependent variable yields the following equation:

$$I_{SC} = 0.179A^{-0.5708} \tag{4}$$

where

A = lot size (acres per home)
I_{SC} = impervious surface cover expressed as a fraction.

Equation 4 can be rearranged to express the lot size as a function of impervious surface cover. In this case the expression becomes:

$$A = 0.0492I_{SC}^{-1.75} \tag{5}$$

In table 3 the third column shows the estimated impervious surface cover based on equation 5 and on the lot size in the first column. Figure 1 shows the basic data and a best fit line of impervious surface cover as a function of lot size. Impervious surfaces are proportionally larger on small lots so the effects of accounting for them are more pronounced.

The amount of permeable land (A_p)is the total lot size multiplied by the percent of pervious area. Using equation 5, A_p is be defined as

$$A_p = A(1\text{-}0.179A^{-0.5708}) \tag{6}$$

Substituting equations 2, 3 and 6 into equation 1 yields a modified Trela-Douglas nitrate-dilution equation:

$$HM = A(1\text{-}0.179A^{-0.5708})RC_q \tag{7}$$

Equation (7) may be rewritten to solve for the different unknowns. It would difficult to rewrite this equation to solve for A. It is easy to rewrite to solve for recharge (R). The equation becomes:

$$R = HM /(C_q A(1\text{-}0.179A^{-0.5708})) \tag{8}$$

Equations 8 has not had any units assigned. For example, if the following units and values are used:

Variable	units
H	persons per home
M	pounds per person per year
C_q	mg/L nitrate-nitrogen
A	acres per home
R	inches per year

then the expression for R becomes:

$$R = 4.4186HM / (C_q A(1-0.179A^{-0.5708})) \qquad (9)$$

where 4.4186 is a conversion factor. As an example, if the following values are assumed

H = 3 persons per home
M = 10 pounds per person per year
C_q = 5.2 mg/L
A = 3 acres per home

then R is equal to 9.4 inches/year. Thus, for these assumed values, if a development of 3-acre lots receives 9.4 inches per year of recharge then nitrate (from on-site subsurface wastewater disposal systems) in ground water leaving the development will be diluted to 5.2 mg/L after complete mixing. Receiving less recharge will produce less dilution and result in a greater nitrate concentration.

The values assumed above for housing occupancy rates and nitrate loading rates are average values for New Jersey. Different values yield different results.

Equation 9 allows calculation of recharge based on other input parameters. The equation is in this form, instead of being solved for lot size, in order to facilitate plotting of the solution. These results are shown in figure 2 and in table 4. In table 4 the necessary recharge is shown for a nitrate target of 5.2 mg/l.

Limiting Assumptions

The assumption that the entire lot contributes recharge to dilute the effluent emanating from an on-site subsurface waste-water disposal system is not exactly accurate. The plume from an individual system is diluted by recharge which falls upgradient or downgradient of the tank. Thus the Trela-Douglas method cannot accurately estimate nitrate concentrations downgradient of an on-site subsurface wastewater disposal system on any individual lot. On a larger scale, however, it can adequately estimate the effect of multiple disposal systems on water quality downgradient of a housing development.

The model does not correct for nitrate dilution by ground water flowing under the lot from the upgradient direction. This is ignored because the concentration of background nitrate may vary. If the system is planned using some dilution from this upgradient water, then any worsening of quality may cause the nitrate target not to be met. In short, the only water than can be relied on in estimating nitrate dilution is recharge generated on the lot.

Table 3. Lot size and impervious cover relationship

Lot Size (acres per home)	Impervious Cover	
	from TR-55[a] (percent)	Estimated from equation 7 (percent)
0.13	65%	59%
0.25	38%	39%
0.33	30%	34%
0.5	25%	27%
1	20%	18%
2	12%	12%

a) U.S. Dept. of Agriculture, 1986.

Table 4. Lot size, impervious cover, and recharge required to meet nitrate target.

Lot size (acres)	Impervious cover [1] (%)	Recharge rate (in/yr) required to meet nitrate target of 5.2 mg/L
20	3.2	5.3
19	3.3	5.4
18	3.4	5.5
17	3.5	5.5
16	3.7	5.7
15	3.8	5.8
14	4.0	5.9
13	4.1	6.1
12	4.3	6.3
11	4.6	6.5
10	4.8	6.7
9	5.1	7.1
8	5.5	7.5
7	5.9	8.0
6	6.4	8.7
5	7.1	9.8
4.5	7.6	10.4
4	8.1	11.3
3.5	8.8	12.4
3	9.6	13.9
2.5	10.6	16.1
2	12.1	19.4
1.5	14.2	25.1
1	17.9	37.1
0.75	21.1	50.0
0.5	26.6	78.2
0.33	33.5	127.0
0.25	39.5	184.3
0.13	58.7	532.1

1. From the relationship between lot size and impervious cover developed for this report.
2. Assuming 3 people per home, and 10 pounds per person per year nitrate loading rate. Note that recharge rates greater than 23 in/year are unlikely in New Jersey.

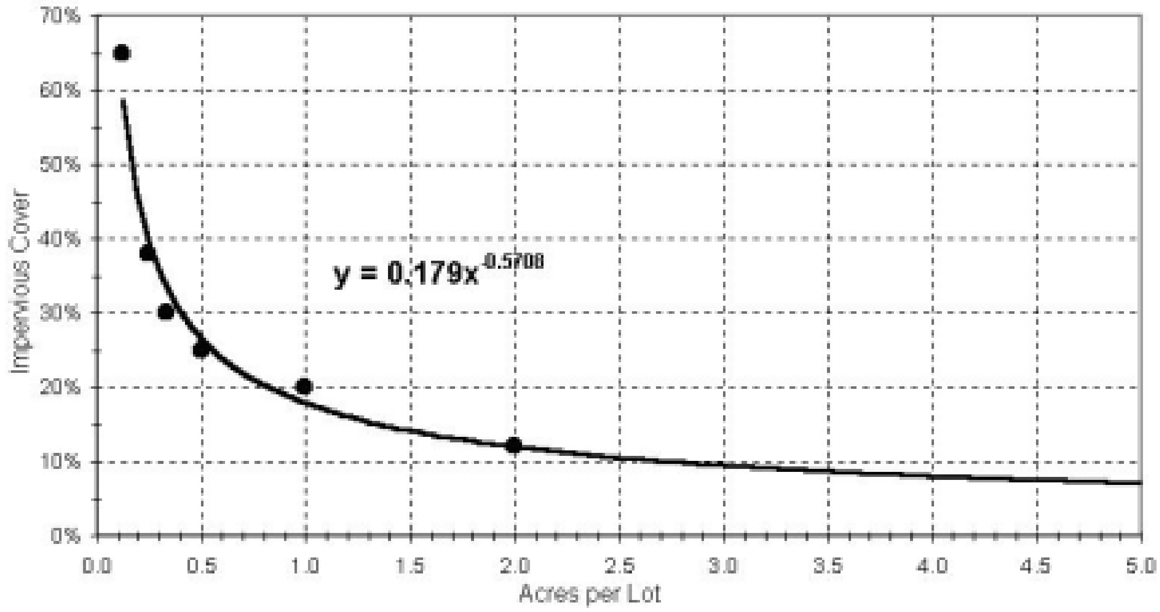

Figure 1. Relation between percentage of land cover and housing density.
Points depict U.S. Dept. of Agriculture (1986) data.
Curve is best fit power series line for the data set.

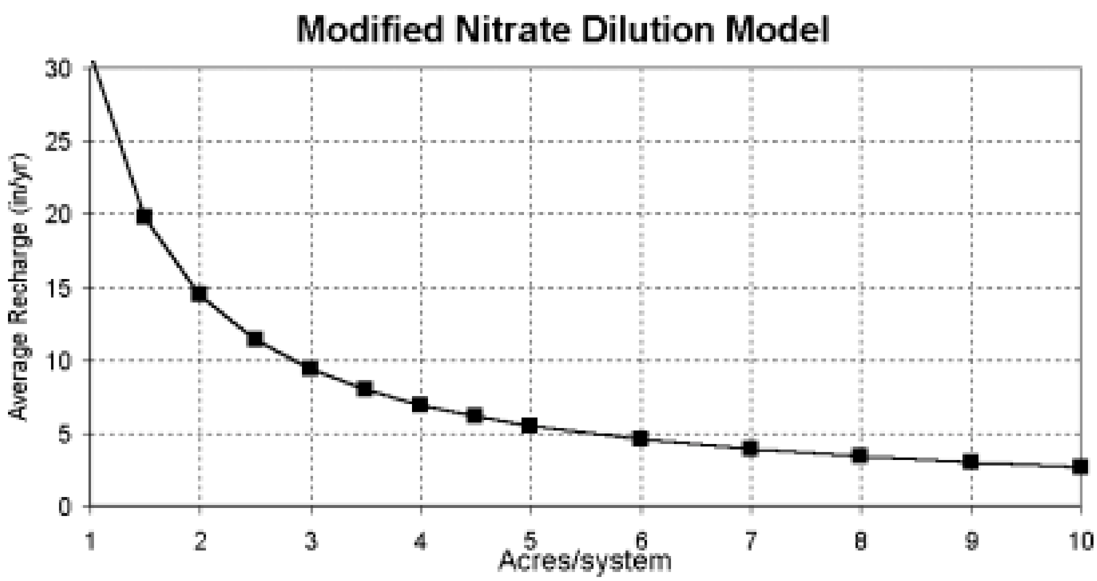

Figure 2. Example of modified Trela-Douglas nitrate-dilution model
Assumptions: 3 people/home, 10 pounds nitrate/person/year

GROUND-WATER RECHARGE MODEL

Ground-water recharge is defined as that water which infiltrates vertically downward from the land surface to below the root zone. Here, water may move laterally to discharge in streams and lakes or downward to enter an aquifer. This water is available to dilute the effluent emerging from an on-site subsurface wastewater disposal system.

Report GSR-32 of the New Jersey Geological Survey, "A method for evaluating ground-water-recharge areas in New Jersey," details one method for evaluating this recharge for land parcels as small as 5 acres (Charles and others, 1993). This method is based on site factors, which are a function of the site's municipality, soil, and land use/land cover (LULC). This method was published in spreadsheet form by Hoffman (1999b). The methodology as developed applies only to New Jersey. The assumptions involved in this model are thoroughly listed in Charles and others (1993).

This method has since been applied several times: in Middlesex County (French, 1996), Cape May County (French and Silvestri, 1999) and the Upper Passaic watershed (N.J. Dept. of Env. Prot., 1998), for example. The NJGS plans to apply this method to all the counties in New Jersey.

When the methodology was first published a basin calibration factor of 1.3 was recommended. This factor calibrates ground-water recharge from an entire basin to base flow measured at a downstream gage. The NJGS currently recommends using a basin factor of 1.0 based on recent calibration of basin-wide recharge volume from this methodology to revised stream baseflow estimations (Hoffman, 1999a).

This method provides an estimate of the ground-water recharge on a parcel of land. It also can be used to estimate changes in recharge resulting from changes in land use. Thus, for example, it can be used to determine how recharge changes following development of a parcel of land.

This method is applied on a municipality and soil-specific basis. For example, estimated ground-water recharge at developed sites in Rockaway Township, Morris County on Rockaway soil, is shown in table 5. Figure 3 shows recharge plotted against impervious cover for this area.

Figure 3 shows that for a specific soil type and municipality, ground-water recharge is assumed to be a linear function of the impervious surface covers. This can be expressed as:

$$R = s(1-I_{SC}) \qquad (10)$$

where

R = recharge (inches per year)
s = maximum recharge assuming 0 percent impervious surface cover (inches per year)
I_{SC} = impervious surface cover expressed as a fraction

As shown in equation 4, the impervious surface cover can be expressed as a function of lot size. Substituting equation 4 into equation 10 results in:

$$R = s(1-0.179A^{-0.5708}) \qquad (11)$$

where A is the lot size in acres per unit. This equation makes it possible to calculate the recharge at developed lots of different sizes. For the example of Rockaway soil in Rockaway Township, with a basin factor of 1.0, the results are shown in figure 4. A similar curve can be developed for any soil and municipality combination in New Jersey.

Table 5. Developed land codes for Rockaway Township, Rockaway soil with estimated impervious cover and ground-water recharge.

Land Use/Land Cover		Impervious cover (percent)	Estimated recharge (inches per year)[a]
code	Description		
0	landscape open space	0	16.5
1	1/8 acre lots	65	5.8
2	1/8 - 1/2 acre lots	33	11.1
3	1/2 - 1 acre lots	23	12.7
4	1 - 2 acre lots	17	13.7
5	developed, landscaped	85	2.5
6	developed, unlandscaped	100	0.0

a) Based on the method of Charles and others, 1993, assuming the basin factor = 1.0.

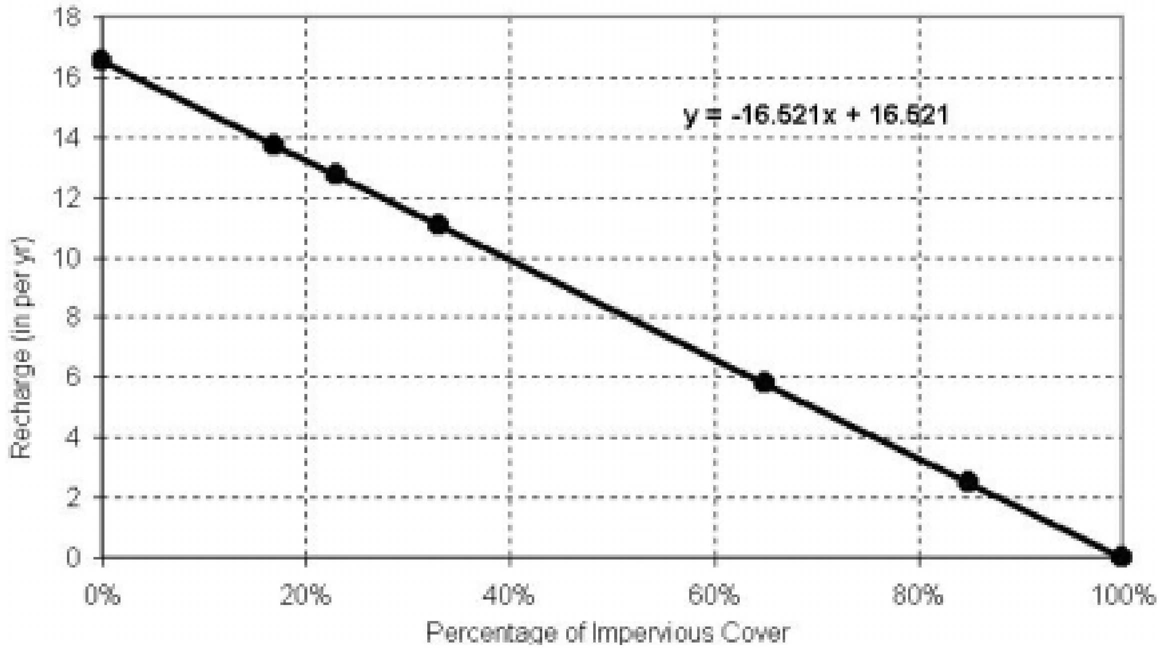

Figure 3. Example of recharge as a function of impervious cover.
(Calculated using the recharge methodology of Charles and others (1993))

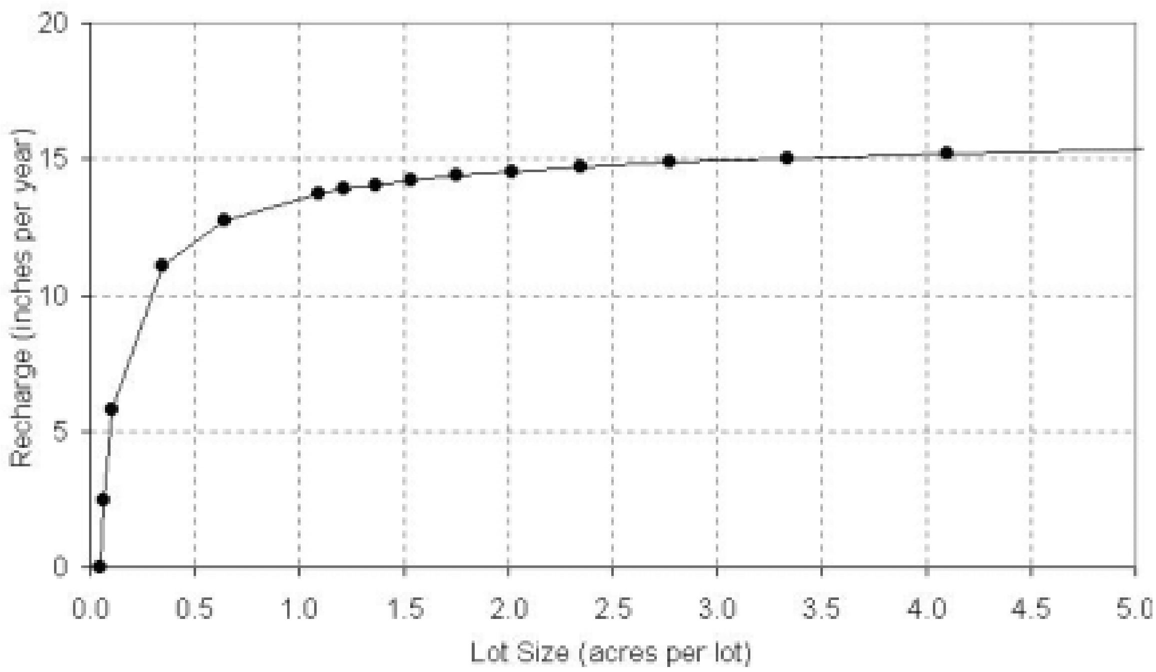

Figure 4. Graph relating recharge to lot size.
(Calculated using the recharge methodology of Charles and others (1993)
This example is for a Rockaway soil in Rockaway Township, Morris County.)

Recharge-Based Nitrogen-Dilution Model

The goal of the recharge-based nitrate-dilution model is to determine, for the specified values, the minimum lot size that will provide sufficient ground-water recharge to dilute the nitrate coming out of the on-site subsurface waste-water disposal system to the target concentration. This is done by merging the Trela-Douglas nitrate-dilution model and the ground-water recharge model of the NJGS.

Model development

The Trela-Douglas nitrate dilution method was rewritten (equation 9) incorporating the relationship between lot size and recharge to facilitate meeting the specified water-quality goal. The relationship between lot size and recharge needed is shown in figure 1 (as the ‘modified for impervious surface cover’ curve) and in table 3.

The NJGS' ground-water recharge methodology (as developed by Charles and others, 1993 and referred to as 'GSR-32') was used (equation 11) to estimate recharge as a function of lot size for a specified municipality and soil. This relationship, for Rockaway soil in Rockaway Township is shown in figure 4.

Merging these two models is equivalent to noting where the curves for recharge vs. land area curves generated from the two methods intersect. The two plots (figs. 1 and 4) are shown in figure 5. The intersection shows the minimum lot size needed.

The crossover point is solved for by setting the two equations equal to each other:

$$4.4186HM / (C_q A(1-0.179A^{-0.5708})) = s(1-0.179A^{-0.5708}) \qquad (12)$$

where the variables are defined as follows:

variable	explanation	Units
H	population density	persons per home
M	per capita nitrate loading rate	pounds per person per year
C_q	target nitrate concentration	mg/L nitrate-nitrogen
A	area per disposal system	acres per home
s	maximum ground-water recharge for specified municipality & soil	inches per year

For the specific values used in this example intersection occurs at 2.0 acres/lot. The combined methodology estimates that smaller lots lack enough recharge to dilute the nitrate to the target concentration. Larger lots dilute the nitrate to a value lower than the water-quality goal and thus provide some safety margin.

Equation 12 can be solved for A in different ways. In the accompanying spreadsheet the equation is solved by an iterative solution approach with limits set on the solution to ensure a realistic result.

Parameter Selection

The user can change 5 parameters in the model - housing occupancy rates, per capita nitrate loading rate, nitrate target, township, and soil. Each is discussed below. If the user plans to submit model results as part of an application then parameter values should be selected after a discussion of appropriate values with Department of Environmental Protection staff at a preapplication meeting.

The housing density rate of 3 people per home is based on state-wide estimates. Different occupancy rates may be appropriate if site-specific data indicate otherwise. Township averages or occupancy rates from nearby similar developments may be appropriate in some cases.

A per capita nitrate loading rate of 10 pounds per person per year is supported by the available data. This number shouldn't be changed by the user.

The user determines the nitrate water-quality target that represents the desired outcome. The selection of a water-quality target of the model should be a function of relevant water-resource policies and standards. Because the model incorporates several limiting assumptions, it is advisable that a safety factor be incorporated into the selection of the water-quality target. The selected target may vary depending on geographic location or predominant land use in the modeled area. In the example above a nitrate target of 5.2 mg/l is used. This arises from an application of New Jersey's antidegradation policy on water quality in areas with surface water classified as FW2 (N.J.A.C. 7:9-6). This number, the "anti-degradation limit," is based on a background nitrate value of 0.4 mg/L and a primary drinking water standard of 10 mg/L. This is nitrate target used by the DEP in the 1990's to evaluate proposed developments of 50 or more units (N.J. Dept. of Env. Prot., 1999). Other nitrate targets may result if other regulatory approaches or standards are more appropriate to a specific area.

The township and soil are used by the ground-water recharge methodology to estimate ground-water recharge. Soils are based on the National Resource Conservation Service's county soil maps. If more than a single soil is encountered on a site, the methodology should be run once for each soil.

The NJGS ground-water recharge methodology calculation incorporates a "basin factor." This is intended as a calibration factor to compare ground-water recharge on a basin-wide basis to base flow observed at a appropriate downstream stream gage (Charles and others, 1993, Hoffman, 1999a). The basin factor is used 'behind-the-scenes' in the spreadsheet. This number should not be changed from a value of 1.0 unless a basin-wide comparison of total ground-water recharge and stream flow from a sufficiently-long data record can be used to justify a basin factor other than 1.0. This calibration may only be applicable on a scale equivalent to the area upstream of the gage used for comparison.

The methodology estimates recharge on the developed site. It is interesting to note that recharge in New Jersey ranges from 0 to about 23 inches per year. Sandy soils in undeveloped areas in northern New Jersey receive about 20 to 23 inches to year. Developed areas, those with less permeable soil, and those in drier portions of the state receive less recharge. These recharge values are annual average values. In reality, this recharge is highly season specific. There is typically little recharge during the summer and early fall. Thus nitrate coming out of the disposal system will be not be diluted by recharge on the lot during this time. Ground-water recharge principally occurs from late fall through late spring. Thus effluent will receive more dilution than is predicted during these seasons. At a sufficient distance downgradient from the lot these differences average out. But immediately downgradient of a single lot there may be significant seasonal variations in nitrate concentrations.

How to use the spreadsheet

The file NJ_NO3_DILUTION_V41.XLS is an EXCEL 97 spreadsheet. When Excel starts to load the file it will indicate that the spreadsheet wants to run macros. The user must indicate that this is acceptable by clicking the 'ok' button because the spreadsheet calculates the minimum lot size by running a macro. Not allowing macros to execute will prevent the spreadsheet from performing as desired.

Additionally, the calculations require access to a special solver routine. The program must have access to the file SOLVER.XLA. This is an add-in file to EXCEL 97 that must be activated by issuing the following commands:

1) On the 'Tools' menu pick the 'Add-Ins' option .
2) Check off the box in front of 'Solver Add-In.' (If this is not an option, use the browse command to locate the file SOLVER.XLA and pick this file.) Then click the 'OK' button.

The spreadsheet cannot perform the mathematics necessary to calculate the area if this add-in is not accessible. When the spreadsheet is opened for the first time the screen should look like figure 6. The user inputs the basic parameters needed by the Trela-Douglas and ground-water recharge methodologies via this screen. Soil type and municipalities are specified by clicking on the cell, activating a pull-down menu and picking the appropriate value.

The 'metadata' window has a more comprehensive description of the methodology. This window is not displayed initially. To see it the user must turn off the spreadsheet's protection and then display it.

The calculation window does not automatically update the appropriate lot size as parameters are entered. The user must click on the blue 'Solve' box to do this. This runs an Excel macro which calculates the appropriate area. The macro responds with a command box titled 'Solver Results.' If the solver finds an acceptable solution the user should indicate in this command to "Keep Solver Solution" and then click on the "ok" button (fig. 7).

The user can print out a page summarizing the results on the computer's default printer by clicking on the blue 'Print Results' box.

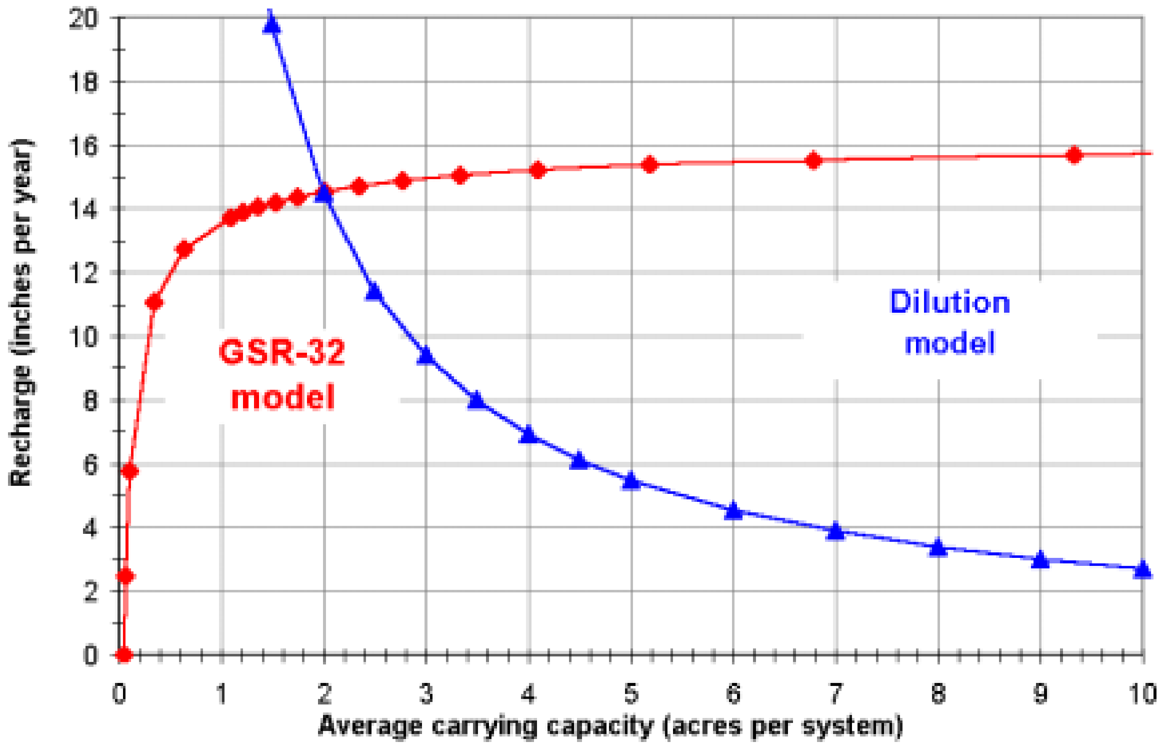

Figure 5. Recharge values estimated by the nitrate-dilution and recharge methodologies.

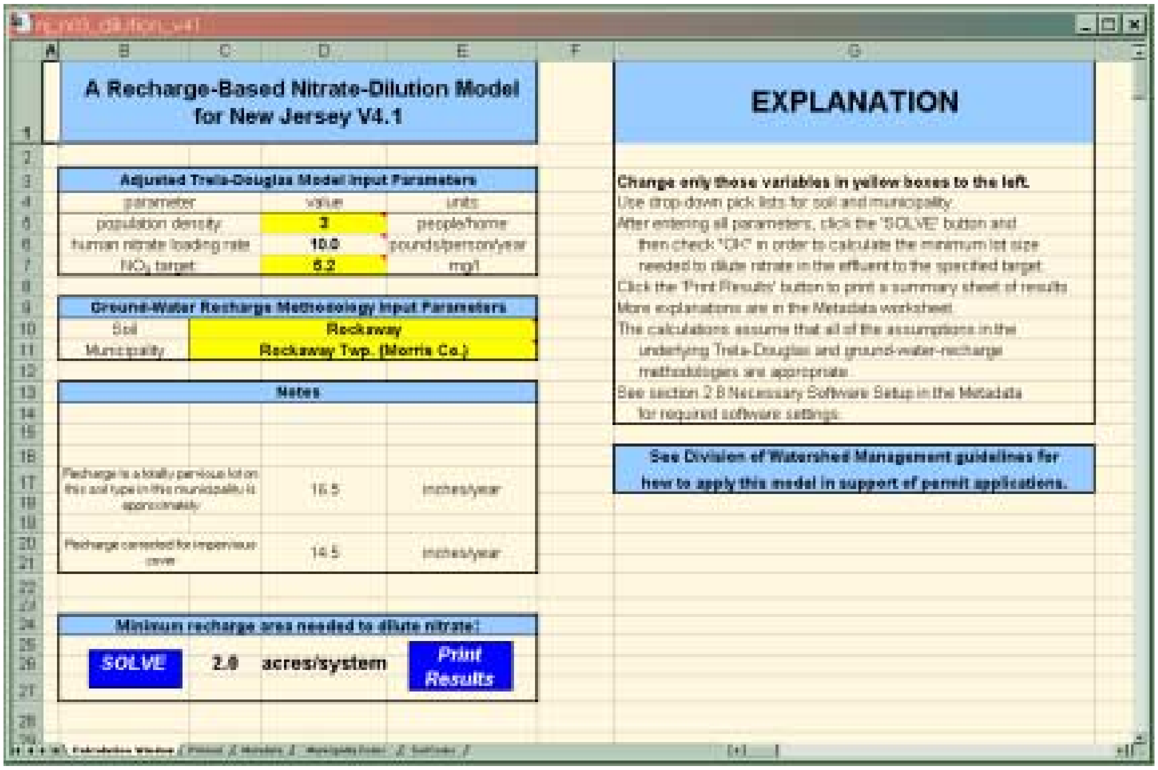

Figure 6. Opening screen of the file NJ_NO3_DILUTION_41.XLS.

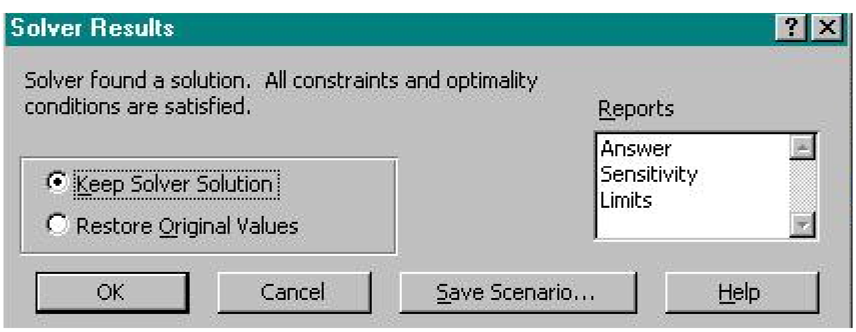

Figure 7. Solver results screen of NJ_NO3_ DILUTION_41.XLS.

SUMMARY

This report presents a recharge-based nitrate-dilution model based on water quality. Nitrate-nitrogen is used as the indicator of water quality. The estimated area, expressed in acres per system, indicates the minimum amount of land required to dilute the nitrate in effluent discharging from an individual domestic on-site subsurface wastewater disposal systems to a specified concentration. The model is designed to estimate the cumulative impact of development on nitrate concentrations in ground water. It is not intended to be used to estimate nitrate concentrations at specific locations downgradient of an individual system.

The required area is generated using a methodology that merges a modified Trela-Douglas nitrate dilution model and the New Jersey Geological Survey's ground-water recharge model. The assumptions used by these underlying models carry over to the nitrate-dilution methodology.

Nitrate-nitrogen is selected for two reasons. The potable-water standard for nitrate-nitrogen is 10 mg/L; higher concentrations may cause methemoglobinemia in infants. Nitrate is stable in ground water and elevated levels may be used as an indicator of human impact on the environment. In addition, nitrate is sometimes used as an indicator of the possible presence of other contaminants in ground water, such as pesticides.

The recharge-based nitrate-dilution model requires specifying the occupancy rate, per capita nitrate loading rate rate, municipality, soil type and target nitrate concentration in ground water. An EXCEL spreadsheet is provided to perform the necessary calculations.

If the input variables are 3 persons per home, 10 pounds of nitrate per person per year in the disposal system's effluent, and a nitrate criterion of 5.2 mg/L in ground water, the model predicts that the minimum required area is about 1.7 acres per home on the sandy soils of northwestern New Jersey. On less permeable soils and in drier parts of the state, more land is needed per disposal system to dilute the nitrate in the effluent to the target concentration. For example, with the same input parameters, the estimated required area on sandy soils in Cape May (an area with less ground water recharge) on sandy soils is about 2.5 acres per home.

The model results are very sensitive to the selected nitrate target. The target concentration should depend on the goal of the user. If the goal is to maintain ambient ground-water quality in undeveloped areas the user might select a concentration of 1 to 3 mg/L nitrate. For areas experiencing build-out, the ambient concentration of nitrates in ground water is likely to be close to 3 mg/L in most cases; this may be an appropriate target in these areas if no further degradation of ground-water quality is the goal. Use of 10 mg/L as the target would appear to protect drinking-water quality, but would provide no safety factors to account for the inability of the model to simulate the actual behavior of waste-

water plumes in ground water. The target concentration should be based on the specific water-quality goals of the user and on state regulations and policies designed to protect water quality.

GLOSSARY

aerobic – Requiring, or capable of living in, the presence of oxygen.

ambient – Generally the conditions uninfluenced by human activities. May refer to conditions before being influenced by the activity under study.

ammonia – As used in this report the aqueous ionic compound of nitrogen and hydrogen expressed as NH_4^+. Also refers to the gas NH_3.

ammonium-nitrogen - A measure of the concentration of nitrogen found in ammonia.

anaerobic – Requiring, or capable of living in, the absence of oxygen.

aquifer - A formation, group of formations, part of a formation or interconnected fractured bedrock, capable of supplying useful quantities of water to wells and springs.

anionic – A compound with a negative ionic charge.

carrying capacity – A measure of how much activity a particular resource can withstand before it is affected beyond a set amount.

cationic – A compound with a positive ionic charge.

contaminant plume – An identifiable area downgradient of a contamination source which has become contaminated.

criteria, water quality – The designated levels or concentrations of constituents that, when not exceeded, will not prohibit or significantly impair a designated use of water.

denitrification – The process by which nitrite and nitrate is converted into nitrogen gas.

dispersion - The process whereby a solute in flowing ground water is mixed with adjacent water and thereby becomes reduced in concentration.

diffusion - The process by which solutes in water move from areas of higher concentration to areas of lower concentration.

dinitrogen gas – N_2 **–** The most common form in which nitrogen is found in nature. Most of the earth's atmosphere consists of N_2.

dissolved oxygen - The amount of oxygen dissolved in water, by weight.

downgradient – The area ‘downhill’ of a specific site. In a ground-water sense, this is the area to which the ground water is flowing.

electron donor – A chemical which, during an oxidation reaction, gives up an electron.

electron receptor - A chemical which, during an oxidation reaction, receives an electron.

gradient - The degree of inclination of a surface.

impervious cover – Part of the land surface which does not allow recharge. For example, roof tops and paved areas.

inorganic – A chemical or process which does not involve carbon.

Kjeldahl nitrogen - This is a measure of both the ammonia and the organic forms of nitrogen.

labile – Chemically reactive or unstable mechanically.

leachate – Liquid produced during the decomposition of matter.

leachate field – A system of horizontal pipes which distribute the leachate discharging from an on-site subsurface waste-water-disposal system over a wider area to facilitate treatment.

median – The value in a set of numbers such that half of the numbers are greater and half lower. For example, in the set of numbers 1,2,2,3,4,78,100 the median value is 3.

nitrogen (organic) – Amino acids, polypeptides, proteins and albuminoid nitrogen contribute to the organic nitrogen content of the water. A rise in the organic nitrogen content may indicate sewage or industrial-waste pollution.

nitrate – NO_3 – The most highly oxidized form of nitrogen in the nitrogen cycle. It is generally nonreactive and moves readily in water.

nitrite – NO_2 – This form of nitrogen is generally unstable in aerobic environments. In most ground and surface waters it is a negligible constituent.

nitrification – Generally, the process by which nitrogen is converted by soil bacteria into nitrite and nitrate.

organic – A chemical or reaction which involves carbon.

oxidization – A chemical reaction in which an element loses an electron.

oxidized – A chemical which has gone through an oxidation reaction and lost an electron.

physiographic province – An area with distinct and characteristic landforms.

PRM - The Potomac-Raritan-Magothy formation. It is a major aquifer in southern New Jersey.

recharge – The process of addition of water to the saturated zone; also the water added.

reduction – A chemical reaction in which an element gains an electron.

septic tank – An underground tank designed to hold household sewage waste and its decomposition products. It commonly is connected to a series of pipes (‘leachate field’) to allow liquid to exit the tank to the ground.

slug – A measurable pocket of contaminated water moving with the water flow.

standard – The concentration which may not be exceeded by a specific activity based on state regulations.

upgradient – The area ‘uphill’ of a specific site. In a ground-water sense, this is the area from which the ground water is flowing.

water table - The upper surface of a zone of saturation except where that surface is formed by a confining unit. The upper surface of the zone of saturation at which the water pressure in the porous medium equals atmospheric pressure.

REFERENCES

Barringer, J.L., MacLeod, C.L., and Gallagher, R.A., 1997, Mercury in ground water, soils, and sediments of the Kirkwood-Cohansey aquifer system in the New Jersey Coastal Plain: U.S. Geological Survey Open-File Report 95-475, West Trenton, N.J., 260 p.

Barton, Cynthia, Vowinkel, E.F., and Nawyn, J.P., 1987, Preliminary assessment of water quality and its relation to hydrogeology and land use: Potomac-Raritan-Magothy aquifer system, New Jersey: U.S. Geological Survey Water-Resources Investigations Report 87-4023, West Trenton, N.J., 79 p.

Bowers, F.H., 1999, Septic systems and nitrate nitrogen as indicators of ground water quality trends in New Jersey: N.J. Department of Environmental Protection, Division of Water Quality, Trenton, N.J., 5p.

Carleton, G.B. and Vowinkel, E.F., 1996, Nitrate in ground water and surface water in a residential subdivision, West Windsor Township, Mercer County, New Jersey, 1993: U.S. Geological Survey Open-File Report 96-576, West Trenton, N.J., 33 p.

Chapelle, F.H., 1997, The hidden sea - ground water, springs and wells: Tucson, AZ, Geoscience Press, 238p.

Charles, E.G., Behroozi, Cyrus, Schooley, Jack, and Hoffman, J.L., 1993, A method for evaluating ground-water-recharge areas in New Jersey: N.J. Geological Survey Report GSR-32, Trenton, N.J., 95p.

Czarnik, T.S. and Kozinski, Jane, 1994, Ground-water quality in the central part of the Passaic River Basin, northeastern New Jersey, 1959-88: U.S. Geological Survey Water-Resources Investigations Report 92-4083, West Trenton, N.J., 66 p.

Desimone, L.A. and Barlow, P.M., 1996, A nitrogen-rich septage-effluent plume in a glacial aquifer, Cape Cod, Massachusetts, February 1990 through December 1992, U.S. Geological Survey Water-Supply Paper 2456, 89 p.

Ervin, Elizabeth, Voronin L.M.., and Fusillo, T.V., 1994, Water quality of the Potomac-Raritan-Magothy aquifer system in the Coastal Plain of New Jersey: U.S. Geological Survey Water-Resources Investigations Report 94-4113, West Trenton, N.J., 114 p.

Firestone, M.K., 1982, Biological denitrification: in Nitrogen in Agricultural Soils, Stevenson, F.J. editor, American Society of Agronomy, Madison, Wis., pp. 289-326.

Foster, S.S.D., Kelly, D.P. and James, R., 1985, The evidence for zones of denitrification in British aquifers: in Planetary Ecology, Caldwell, D.E., Brierley, J.A. and Brierley, C.L., editors, Van Nostrand Reinhod, NY, pp. 356-369.

French, M.A., 1996, Ground-water recharge and aquifer recharge potential for Middlesex County, New Jersey: N.J. Geological Survey Open-File Map OFM 21, Trenton, N.J., 1 pl., scale 1:250,000.

French, Mark A. and Silvestri, ShayMaria, 1999, Ground-Water Recharge and Aquifer Recharge Potential for Cape May County, New Jersey: N.J. Geological Survey Open-File Map OFM 31, 1 pl., scale 1 to 100,000.

Fusillo, T.V., Hochreiter, J.J., and Lord, D.G., 1984, Water-quality data for the Potomac-Raritan-Magothy aquifer system in southwestern New Jersey, 1923-83: U.S. Geological Survey Open-File Report 84-737, Trenton, N.J., 1984, 127 p, 1 pl.

Fusillio, T.V. and Voronin, L.M., 1981, Water-quality data for the Potomac-Raritan-Magothy aquifer system, Trenton to Pennsville, New Jersey, 1980: U.S. Geological Survey Open-File Report 81-814, Trenton, N.J., 38 p, 2 pls.

Gillham, R.W. and Cherry, J.A., 1978, Field evidence of denitrification in shallow groundwater flow systems: Water Pollut. Res. Can., 13(1), p.53-71.

Hantzsche, N.N. and Finnemore, E.J., 1992, Predicting ground-water nitrate-nitrogen impacts: Ground Water, v. 30, no. 4, July-Aug. 1992, p. 490-499.

Harriman, D.A., Pope, D.A., and Gordon, A.D., 1989, Water-quality data for the Potomac-Raritan-Magothy aquifer system in the northern Coastal Plain of New Jersey, 1923-86: N.J. Geological Survey Geological Survey Report 19, Trenton, N.J., 94 p, 2 pls,

Harriman, D.A. and Voronin, L.M., 1985, Water-quality data for aquifers in east-central New Jersey, 1981-82: U.S. Geological Survey Water-Resources Investigations Report 85-4243, West Trenton, N.J., 114 p., 1 pl.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water, (3 ed.) : U.S. Geological Survey Water-Supply Paper 2254, 264p, 2 pls.

Herman, G.C., Canace, R.J., Stanford, S.D., Pristas, R.S., Sugarman, P.J., French, M.A., Hoffman, J.L., Serfes, M.S., and Mennel, W.J., 1998, Aquifers of New Jersey: N.J. Geological Survey Open-File Map OFM-24, scale 1:500,000

Hiscock, K.M., Lloyd, J.W., and Lerner, D.N., 1991, Review of natural and artificial denitrification of groundwater: Water Resources, v. 25, no. 9, Univ. of E. Anglia, Norwich, England, p. 1099-1991.

Hoffman, J.L., 1999a, Basin factor calibration for ground-water-recharge estimation: N.J. Geological Survey Technical Memorandum TM 99-1, Trenton, N.J., 2p.

----,1999b, Spreadsheet for ground-water recharge calculations in New Jersey: N.J. Geological Survey Digital Geodata Series DGS 99-2, Trenton, N.J..

Johnson, M.L. and Watt, M.K., 1996, Hydrology of the unconfined aquifer system, Mullica River Basin, New Jersey, 1991-92: U.S. Geological Survey Water-Resources Investigations Report 94-4234, West Trenton, N.J., 6 sheets.

Johnson, Patricia and Barringer, J.L., 1993, Water quality and hydrogeochemical processes in McDonalds Branch Basin, New Jersey Pinelands, 1984-88: U.S. Geological Survey Water-Resources Investigations Report 91-4081, West Trenton, N.J., 111 p.

Kasabach, Haig F., 1966, Geology and ground water resources of Hunterdon County, New Jersey: N.J. Geological Survey Special Report No. 24, Trenton, N.J., 128 p., 2 pl.

Knobel, L.L., 1985, Ground-water-quality data for the Atlantic Coastal Plain - New Jersey, Delaware, Maryland, Virginia and North Carolina: U.S. Geological Survey Open-File Report 85-154, Trenton, N.J., 84 p., 1 pl.

Korom, S.F., 1992, Natural denitrification in the saturated zone, A review: Water Resources Research, v. 28, no. 6, p. 1657-1688, June 1992.

Kozinski, Jane, Szabo, Zoltan, Zapecza, O.S., and Barringer, T.H., 1995, Natural radioactivity in, and inorganic chemistry of, ground water in the Kirkwood-Cohansey aquifer system, southern New Jersey, 1983-89: U.S. Geological Survey Water-Resources Investigation Report 92-4144, West Trenton, N.J., 130 p.

Laak, Rein, 1980, Wastewater engineering design for unsewered areas: Ann Arbor, Ann Arbor Science Publishers, Inc., 179 p.

Lacombe, P.J. and Rosman, Robert, 1995, Hydrology of the unconfined aquifer system in the upper Maurice River Basin and adjacent areas in Gloucester County, New Jersey, 1986-87: U.S. Geological Survey Water-Resources Investigation Report 92-4128, West Trenton, N.J., 5 sheets.

LeBlanc, D.R. 1984, Sewage plume in a sand and gravel aquifer, Cape Cod, Massachusetts: U.S. Geological Survey Water-Supply Paper 2218, Reston, VA, 28 p.

Ligman, Kenneth, Huztler, Neil and Boyle, W.C., 1974, Household wastewater characterization: Journal of the Environmental Engineering Division, Proceedings of the American Society of Civil Engineers, v. 100, no. EE1, pp. 201-213.

Lord, D.G., Barringer, J.L., Johnsson, P.A., Schuster, P.F., Walker, R.L, Fairchild, J.E., Sroka, B.N. and Jacobsen, Eric, 1990, Hydrogeochemical data from an acidic deposition study at McDonalds Branch Basin in the New Jersey Pinelands, 1983-86: U.S. Geological Survey Open-File Report 88-500, West Trenton, N.J., 132 p.

MacLeod, C.L., Barringer T.H., Vowinkel, E.F., and Price, C.V., 1995, Relation of nitrate concentrations in ground water to well depth, well use, and land use in Franklin Township, Gloucester County, New Jersey, 1970-85: U.S. Geological Survey Water-Resources Investigations Report 94-4174, West Trenton, N.J., 29 p.

Metcalf & Eddy, Inc., 1991, Wastewater engineering (3rd ed.): New York, McGraw-Hill, Inc., 1334 p.

Miller, J.W., 1974, Geology and ground water resources of Sussex County and the Warren County portion of the Tocks Island impact area: N.J. Geological Survey Bulletin 73, Trenton, N.J., 143 p., 2 pls.

Murphy, E.A, 1992, Nitrate in drinking water wells in Burlington and Mercer Counties, N.J.: Journal of Soil and Water Conservation, v. 47, no. 2, p. 183-187.

National Atmospheric Deposition Program, 1998, National Atmospheric Deposition Program 1997 Wet Deposition: Illinois State Water Survey, Champaign, IL, 16 p.

New Jersey Department of Environmental Protection, 1998, Initial watershed characterization and assessment of the Upper Passaic Whippany and Rockaway Watersheds, Chapter 3, Section 3.2, Water Quantity Issues: Division of Watershed Management, Trenton, N.J., 60p.

---, 1999, Guidance for 50 or more realty improvement certifications: Division of Water Quality, Bureau of Nonpoint Pollution Control, Trenton, N.J., 17p.

Nicholson, R.S. , McAuley, S.D., Barringer, J.L. and Gordon, A.D., 1996, Hydrogeology of, and ground-water flow in, valley-fill and carbonate-rock aquifer system near Long Valley in the New Jersey Highlands: U.S. Geological Survey Water-Resources Investigation Report 93-4157, West Trenton, N.J., 159 p, 3 pls.

Saunders, W.R., Trela, J.J., and Benintente, J.A., 1979, Water quality and septic systems, Ocean Acres subdivision, Stafford and Barnegat Townships, Ocean County, New Jersey: technical report prepared for the Bureau of Water Quality Planning and Management, Division of Water Resources, N.J. Department of Environmental Protection, Trenton, N.J., 19p.

Serfes, M.E., 1994, Natural ground-water quality in bedrock of the Newark Basin, New Jersey: N.J. Geological Survey Report GSR-35, Trenton, N.J., 28 p.

----, in press, Ground-water quality in the bedrock aquifers of the Highlands and Valley and Ridge physiographic provinces of New Jersey: N.J. Geological Survey Geologic Report Series 39, Trenton, N.J.

Siegrist, Robert, Witt, Michael and Boyle, W.C., 1976, Characteristics of rural household wastewater: Journal of the Environmental Engineering Division, Proceedings of the American Society of Civil Engineers, v. 102, no. EE3, pp. 533-548 .

Stackelberg, P.E., Hopple, J.A. and Kauffman, L.J., 1997, Occurrence of nitrate, pesticides, and volatile organic compounds in the Kirkood-Cohansey aquifer system, southern New Jersey: U.S. Geological Survey Water-Resources Investigations Report 97-4241, West Trenton, N.J., 8p.

Szabo, Zoltan, Rice, D.E., MacLeod, C.L., and Barringer, T.H., 1997, Relation of distribution of radium, nitrate, and pesticides to agricultural land use and depth, Kirkwood-Cohansey aquifer system, New Jersey Coastal Plain, 1990-91: U.S. Geological Survey Water-Resources Investigations Report 96-4165A, West Trenton, N.J., 119 p.

Thurman, E.M, 1985, Organic Geochemistry of Natural Waters: Nijhoff-Junk, Dordrecht.

Tinker, J.R. Jr., 1991, An analysis of nitrate-nitrogen in ground water beneath unsewered subdivisions: Ground Water Monitoring Review, National Ground Water Association, Columbus, Ohio, Winter 1991, p. 141-150.

Todd, D.K., and McNulty, D.E., 1974, Polluted groundwater - A review of the significant literature: USEPA Report EPA-600/4-74-001, Washington DC, March 1974, 215 p.

Trela, J.J., and Douglas, L.A., 1978, Soils, septic systems and carrying capacity in the New Jersey Pine Barrens: paper presented at the First Annual Pine Barrens Research Conference, Atlantic City, N.J., May 22, 1978, 34 p.

U.S. Department of Agriculture, Soil Conservation Service, 1986, Urban Hydrology for small watersheds, 2nd ed.: Technical Report 55, 156 p.

U.S. Environmental Protection Agency, 1980, Design manual-onsite wastewater treatment and disposal systems: Office of Water Program Operations and Office of Research and Development, ?.

U.S. Geological Survey, 1999, The quality of our nation’s waters – Nutrients and pesticides: U.S. Geological Survey Circular 1225, 82 p.

Vowinkel, E.F. and Tapper, R.J., 1995, Indicators of the sources and distribution of nitrate in water from shallow domestic wells in agricultural areas of the New Jersey

Coastal Plain: U.S. Geological Survey Water-Resources Investigations Report 93-4178, West Trenton, N.J., 48 p.

Walker, W.G., Bouma, J., Keeney, D.R., and Magdoff, F.R., 1973a, Nitrogen transformations during subsurface disposal of septic tank effluent in sands, I: Soil transformation: Journal of Environmental Quality, v. 2, no. 4, p. 475-480.

Walker, W.G., Bouma, J., Keeney, D.R., and Olcott, P.G., 1973b, Nitrogen transformations during subsurface disposal of septic tank effluent in sands II. Ground water quality: Journal of Environmental Quality, v. 2, no. 4, p. 521-525.

Watt, M.K. and Johnson, M.L., 1992, Water Resources of the unconfined aquifer system of the Great Egg Harbor River Basin, New Jersey, 1989-90: U.S. Geological Survey Water-Resources Investigations Report 91-4126, West Trenton, N.J., 5 sheets.

Watt, M.K., Johnson, M.L., and Lacombe, P.J., 1994, Hydrology of the unconfined aquifer system, Toms River, Metedeconk River, and Kettle Creek Basins, New Jersey, 1987-90: U.S. Geological Survey Water-Resources Investigations Report 93-4110, West Trenton, N.J., 5 sheets.

Wehrmann, H.A., 1983, Potential nitrate contamination of ground water in the Roscoe Area, Winnebago County, Illinois: report prepared for the Winnebago County Board and the Illinois Department of Energy and Natural Resources by the Illinois State Water Survey, Champaign, Illinois, 108p.

Widmer, Kemble, 1965, Geology and ground water resources of Mercer County, N.J.: N.J. Geological Survey Geologic Report Series No. 7, Trenton, N.J., 115 p., 5 pls.